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CALCULATION OF STREAMLINES ON THE USNS DUTTON.(U)
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DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Md. 20084

CALCULATION OF STREAMLINES ON THE USNS DUTTON

by

H.T. Wang, C.W. Dawson, and N.M. White

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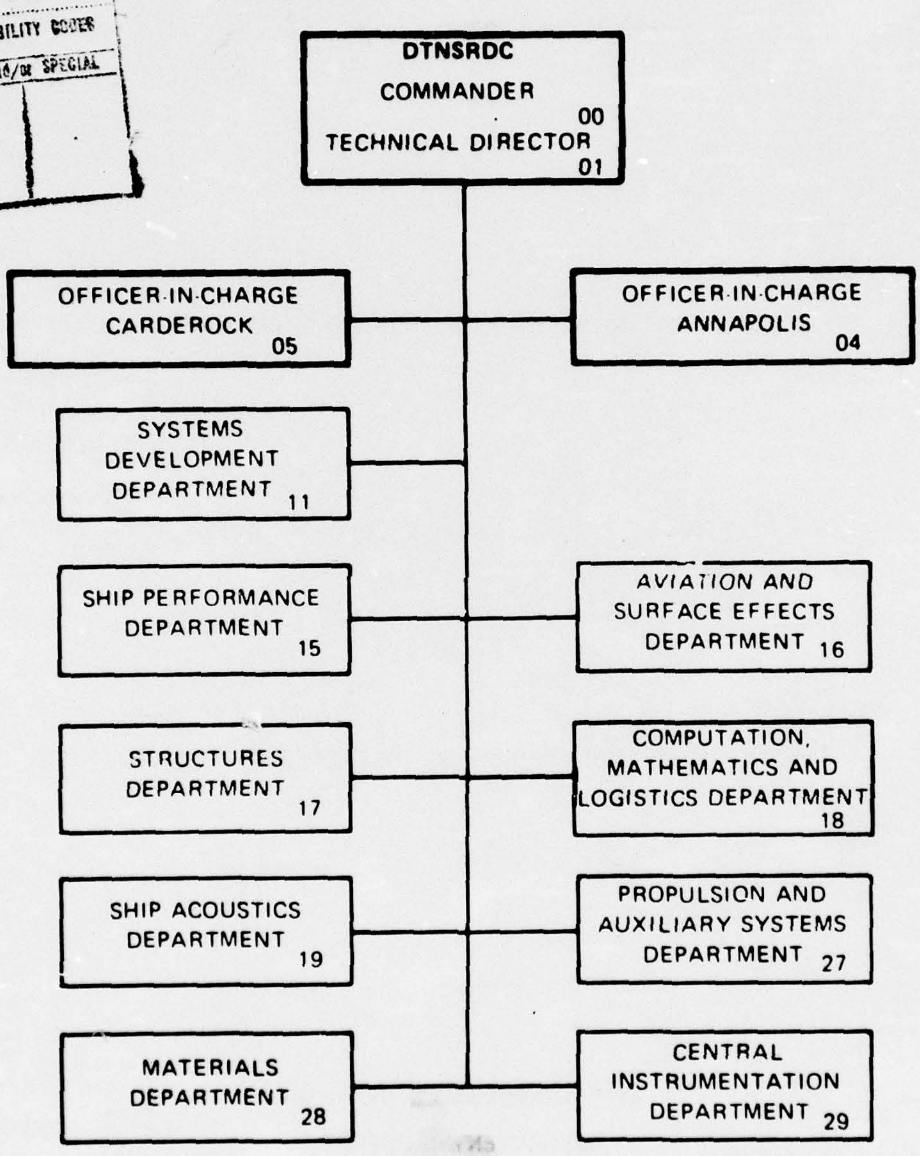

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Four computer calculations were made of the paths of streamlines on the hull of the USNS DUTTON, with and without a proposed keel sonar dome located on the ship's forebody. The calculations employed a potential flow computer program in which the free surface must be treated as a plane of symmetry, and a newer version of this program which can account for free-surface effects. Numerous computer-generated figures of the ship lines and streamlines are presented. The results are briefly discussed. The calculations show that the streamlines which pass through the region of a keel-mounted acoustic receiver

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ABSTRACT

Four computer calculations were made of the paths of streamlines on the hull of the USNS DUTTON, with and without a proposed keel sonar dome located on the ship's forebody. The calculations employed a potential flow computer program in which the free surface must be treated as a plane of symmetry, and a newer version of this program which can account for free-surface effects. Numerous computer-generated figures of the ship lines and streamlines are presented. The results are briefly discussed. The calculations show that the streamlines which pass through the region of a keel-mounted acoustic receiver array located near amidships get no closer than six or seven feet to the ocean surface. Thus, air bubbles originating in the stem or bow region should not be swept past the receiver array by the streamlines and should not degrade receiver acoustic performance.

ADMINISTRATIVE INFORMATION

This work was sponsored by the Naval Ocean Research and Development Activity (NORDA) under Work Request WR 70033 of 11 January 1977. The work was performed under internal Work Unit 1552-140.

INTRODUCTION

Code 351 of NORDA requested that the paths of streamlines on the hull of the USNS DUTTON be determined to serve as an indication of the paths of bubbles entrained by the bow wave. The particular concern was that some of the bubbles would pass through the neighborhood of an

acoustic receiver array, thus degrading its acoustic performance. The USNS DUTTON (T-AGS 22) is a modified Victory ship used by NORDA for oceanographic research. It has a length of 425 ft (129.5 m) at the 28-foot (8.53 m) Design Waterline and a beam of 62 feet (18.9 m). The receiver array is located on the bottom of the hull, 200 feet (60.9 m) aft of the forward perpendicular and extends 15 feet (4.57 m) on either side of the keel.

The possibility of experimentally determining the paths of the streamlines on a model of the ship was explored. However, no existing model of a Victory ship could be located, and it was found that the cost of building a new model was excessive. Thus, it was decided to use potential flow methods to calculate the streamlines. Such methods are commonly used for these calculations; see for example, References 1 and 2. Four calculations were made of the streamlines on the ship with and without a proposed keel sonar dome on the forebody, with the ocean surface treated as a plane of symmetry and as a free surface at the maximum ship operating speed of 16 knots. Each of these calculations is described in some detail below.

Calculation 1 was made on the ship alone, using the XYZ Potential Flow Program,[3] which is widely used at DTNSRDC. Since this program does not have provisions for free-surface effects, the ocean surface is treated as a plane of symmetry resulting in a "double model" representation. Because the ship-dome configuration has a vertical plane of symmetry, only half of the configuration on one side of this plane was modeled in each of the calculations. For the present calculation, 228 quadrilaterals were used to model the ship's surface.

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[1] Huang, T.T. and C.H. von Kerczek, "Shear Stress and Pressue Distribution on a Surface Ship Model: Theory and Experiment," Ninth ONR Symposium on Naval Hydrodynamics, Vol. 2 (1972), pp. 1963-2007.

[2] von Kerczek, C.H., "Calculation of the Turbulent Boundary Layer on a Ship Hull at Zero Froude Number," Journal of Ship Research, Vol. 17, No. 2 (Jun 1973), pp. 106-120.

[3] Dawson, C.W. and J.S. Dean, "The XYZ Potential Flow Program," Naval Ship R&D Center Report 3892 (Jun 1972).

Calculation 2 was made on the ship with the dome included, again using the XYZ Program. Figure 1 shows side and bottom views of the computer representation of this configuration, along with the coordinate system. The sonar dome was located in a region given by: 94.5 ft (28.8 m) $\leq X \leq$ 117.3 ft (33.75 m), -3.77 ft (-1.15 m) $\leq Y \leq$ 3.77 ft (1.15 m), and -33.2 ft (-10.12 m) $\leq Z \leq$ -28 ft (-8.53 m). Figure 2 shows a close-up isometric of the dome. With the exception of Figure 2, all of the other figures in this report are drawn with the bow to the left. The ship-dome surface configuration was modeled by 368 quadrilaterals.

Calculations 3 and 4 were made on the ship alone using a new version of the XYZ Program developed for free-surface problems. A brief description of this still-experimental program is given in the Appendix. Calculation 3 uses the double-model approximation and is similar to Calculation 1 except that only 144 quadrilaterals were used to model the ship's surface. The ship is modelled in more detail vertically near the free surface but less detail along its length. This calculation was performed for three reasons. First, it is a necessary part of Calculation 4 which follows. Second, this served as a check on the effect of a sparser quadrilateral representation of the ship on the calculated paths of the streamlines. Third, the results when compared with the results of Calculation 4, can be used to directly assess the effect of the free surface.

Calculation 4 was made on the ship alone with free-surface effects included. The ship and free-surface were each represented by 144 quadrilaterals. The Froude number, Fn, that was used corresponded to a ship operating speed of 16 knots.

$$Fn = \frac{U}{\sqrt{gL}} = 0.231 \qquad [1]$$

where U is the ship speed,

g is gravity constant = 32.2 ft/sec^2 (9.81 m/sec^2)

L is the length of the DWL = 425 ft (129.54 m)

PRESENTATION OF RESULTS

Since the principal interest centers on the streamlines which pass through the receiver array region, X = 200 ft (60.96 m), $0 \leq Y \leq 15$ ft (4.57 m), Z = -28.0 ft (-8.53 m), the following philosophy was adopted in tracing the streamlines. Streamlines through fixed points on the surface of the ship at X = 200 ft (60.96 m) were traced to the bow and stern of the ship.

As listed in Table 1, 17 to 22 streamlines were traced in Calculations 1 through 4. They range from Streamline 1, which is 0.1 ft (0.03 m) away from the keel, to Streamline 22, which is 0.5 ft (0.15 m) below the free surface. Streamlines 12 through 22, which pass outboard of the receiver array, are included to give the streamline pattern for the entire ship. For each streamline, Table 1 shows the point of closest approach to the ocean surface in the bow region indicated by Calculations 1 through 4.

In order to show the effect of the dome on the streamlines in its vicinity, Figure 4 shows a bottom view of Streamline 7 (which passes through X = 200 ft (60.96 m), Y = 5.0 ft (1.52 m), Z = -27.8 ft (-8.47 m) traced by Calculations 1 and 2 for 60 ft (18.3 m) $\leq X \leq$ 126 ft (38.4 m).

Figures 5 and 6 respectively show front views of the computer-generated paths of streamlines, with ship lines, given by Calculations 3 (Fn = 0) and 4 (Fn = 0.231). Figures 7 through 12 show side and bottom views of the streamlines only, without ship lines, for Calculations 3 and 4. This was done because the ship lines tend to obstruct the view of the streamlines in these two views. Corresponding views for the double model (Fn = 0) and free surface (Fn = 0.231) cases are shown consecutively to point out the differences between these cases.

DISCUSSION OF RESULTS

The results of Table 1 may be compared in three ways. A comparison of the results for Calculations 1 and 2 shows that the effect of the dome (Calculation 2) for 5 ft (1.53 m) $\leq Y \leq$ 29 ft (8.84 m) is to raise the

streamlines somewhat closer to the ocean surface. The maximum difference of 1 foot (0.3 m) occurs for Streamline 9, Y = 10 ft (3.05 m). A comparison of Calculations 1 and 3 show that the finer grid over the upper part of the ship used in Calculation 3 generally serves to raise the streamlines by somewhat less than 1 foot (0.3 m). A comparison of Calculations 3 and 4 shows that the effect of the free surface is to typically raise the streamlines by about 0.5 feet (0.15 m).

If it is assumed that bubble paths follow the streamlines, the principal practical conclusion to be drawn from Table 1 is that it is unlikely that bubbles originating at the free surface will be swept down into the receiver array region. Streamline 11, which passes through the tip of the receiver array gets no closer than 7 feet (2.14 m) to the ocean surface for the ship-alone free-surface case, Calculation 4. With the dome, which raises Streamline 11 by about 1 foot (0.3 m), the closest approach would be reduced to 6 (1.83 m). The other streamlines which pass through the receiver array, Streamlines 1 to 10, are further removed from the ocean surface.

Figure 4 shows that in the vicinity of the dome, the dome displaces Streamline 7 about 1 foot (0.3 m) outboard. This is also typical for Streamlines 8 to 11. The effect of the dome is less on the higher-numbered streamlines, which are further away from the dome.

Figures 5 and 6 show the front views of the streamlines and ship lines for the double model and free-surface cases, respectively. These figures show that the streamlines for the free surface case are closer to the ocean surface than the corresponding streamlines for the double model case as they approach the vertical centerline, Y = 0. Also, the streamlines for the free-surface case are more kinky near the vertical centerline. This results from not modeling the free surface and ship hull in the bow region by a sufficient number of quadrilaterals. It should be noted that the 288 quadrilaterals used to model the ship and free surface are only four less than the maximum number which may be used by the free-surface program without exceeding the memory capacity of the CDC 6400 computer at DTNSRDC.

The side views shown in Figures 7, 9, and 11 indicate that the streamlines for the double model case smoothly approach the undisturbed ocean surface, Z = 0, as they approach the stem. On the other hand, the streamlines for the free-surface case show kinkiness in the bow region. Also, as shown most clearly in Figures 10 and 12, the upper streamlines experience their closest approach to the undisturbed ocean surface before reaching the stem. The computer output indicates that this occurs approximately 15 feet (4.57 m) aft of the forward perpendicular. This is the region where the free surface has a local peak.

The bottom views shown in Figures 7 through 10 indicate little difference in the horizontal components of the streamline paths for the double model and free-surface cases. Starting from X = 200 feet (61.0 m), most of the streamlines first move away from and then toward the vertical centerplane, Y = 0, as they approach the stem. The streamlines which start very close to Y = 0 are not traced all the way to the stem. In these cases, due to numerical error, the streamlines cross the Y = 0 plane before reaching the stem.

ACKNOWLEDGMENT

The authors wish to thank Mr. Melvin E. Haas who helped to produce the computer-generated figures of the streamlines and ship lines.

REFERENCES

1. Huang, T.T. and C.H. von Kerczek, "Shear Stress and Pressure Distribution on a Surface Ship Model: Theory and Experiment," Ninth ONR Symposium on Naval Hydrodynamics, Vol. 2 (1972), pp. 1963-2007.

2. von Kerczek, C.H., "Calculation of the Turbulent Boundary Layer on a Ship Hull at Zero Froude Number," Journal of Ship Research, Vol. 17, No. 2 (Jun 1973), pp. 106-120.

3. Dawson, C.W. and J.S. Dean, "The XYZ Potential Flow Program," Naval Ship R&D Center Report 3892 (Jun 1972).

TABLE 1

CLOSEST APPROACH OF STREAMLINES (IN FT) TO FREE SURFACE IN BOW REGION

No.	Streamline Location at X=200 ft (61 m)	Calc. 1	Calc. 2	Calc. 3	Calc. 4
1	Y=0.1, Z=-28.0	28.00	27.95	28.00	27.98
2	Y=0.2, Z=-28.0	28.00	28.00	27.96	28.00
3	Y=0.5, Z=-28.0	28.00	27.84	28.00	28.00
4	Y=1.0, Z=-28.0	21.54	**	21.32	20.86
5	Y=2.0, Z=-27.9	18.03	**	17.22	17.04
6	Y=3.0, Z=-27.9	15.79	**	--	--
7	Y=5.0, Z=-27.8	13.50	13.27	12.34	12.22
8	Y=7.0, Z=-27.7	11.99	11.32	10.72	10.47
9	Y=10.0, Z=-27.6	10.35	9.37	9.37	8.91
10	Y=12.0, Z=-27.6	9.41	8.56	8.55	8.01
11	Y=15.0, Z=-27.5*	8.38	7.66	7.50	6.96
12	Y=20.0, Z=-27.3	7.05	6.51	5.87	5.55
13	Y=28.0, Z=-26.6	5.70	5.42	5.04	4.42
14	Y=29.5, Z=-25.1	5.49	5.24	4.87	4.37
15	Y=31.0, Z=-19.0	4.62	4.50	--	3.94
16	Y=31.0, Z=-16.0	3.63	4.12	3.59	3.06
17	Y=31.0, Z=-10.0	1.68	2.18	2.23	2.63
18	Y=31.0, Z=-5.0	0.17	0.59	0.47	2.62
19	Y=31.0, Z=-3.0	0.0	0.02	0.0	0.0
20	Y=31.0, Z=-2.0	0.0	0.01	--	--
21	Y=31.0, Z=-1.0	0.0	0.0	--	--
22	Y=31.0, Z=-0.5	0.0	0.0	--	--

* Streamlines 1 through 11 pass through the receiver array region ($X = 200$ ft, $0 \leq Y \leq 15$ ft, $Z = -28$ ft); Streamlines 12 through 22 are outboard of this area.

** Numerical difficulties were encountered for these streamlines, which were traced onto the surface of the dome.

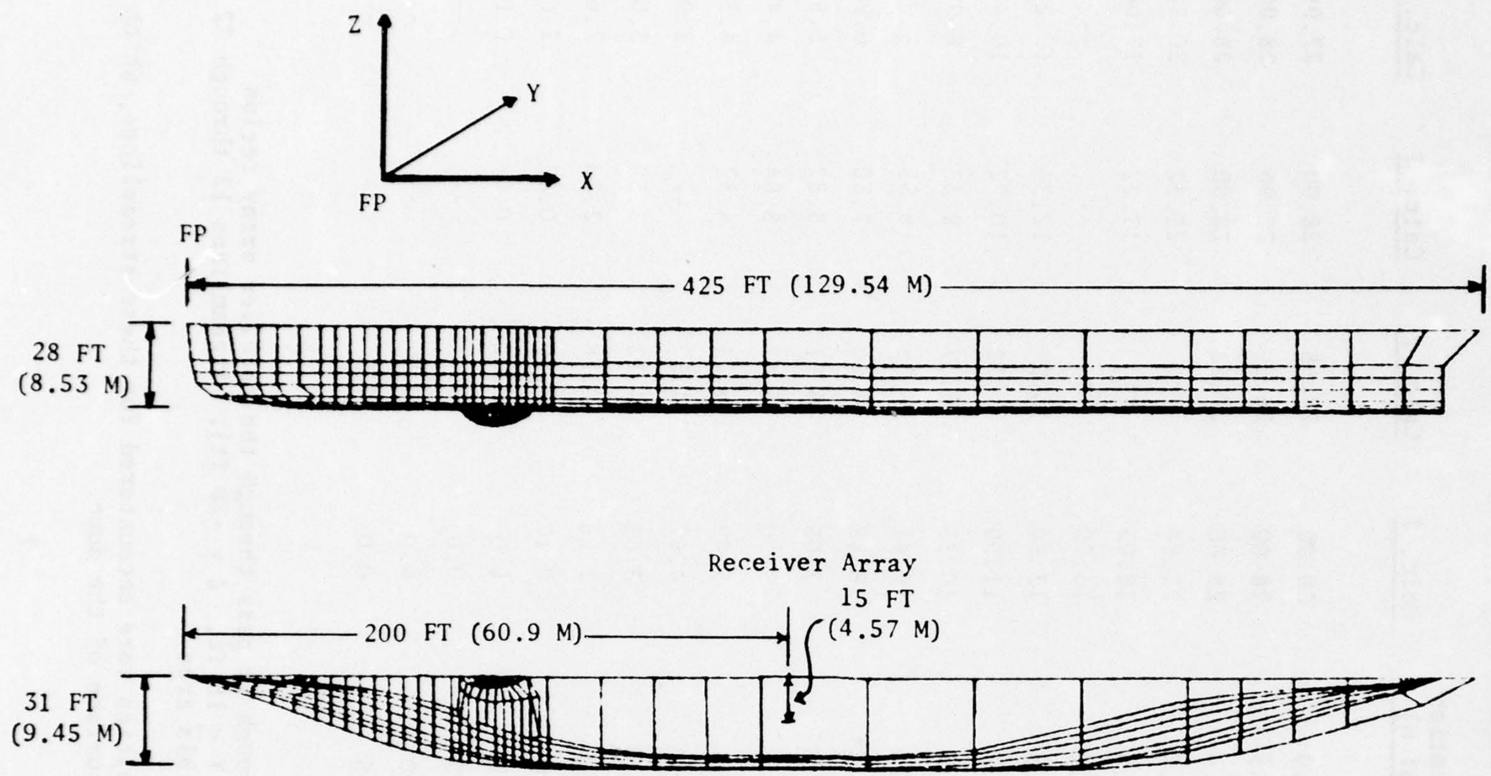


Figure 1 - Side and Bottom Views of Ship-Dome Lines

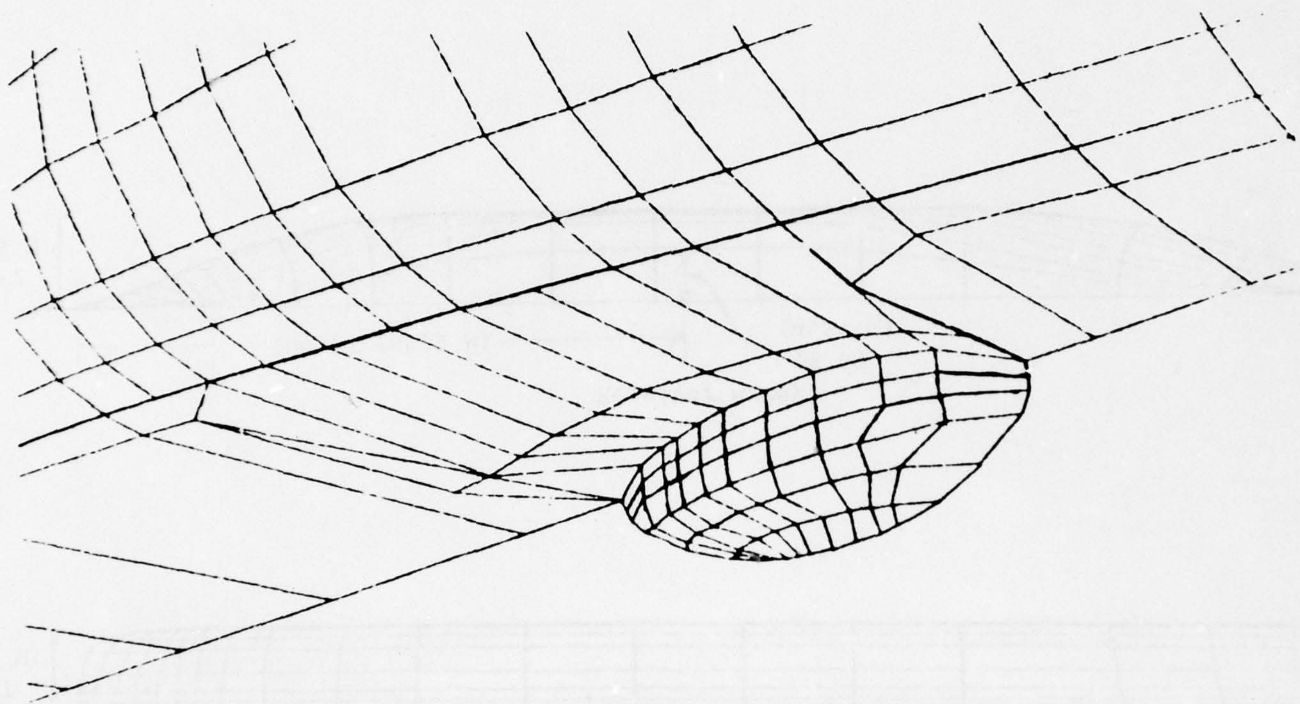


Figure 2 - Isometric View of Dome Lines (Bow to the Right)

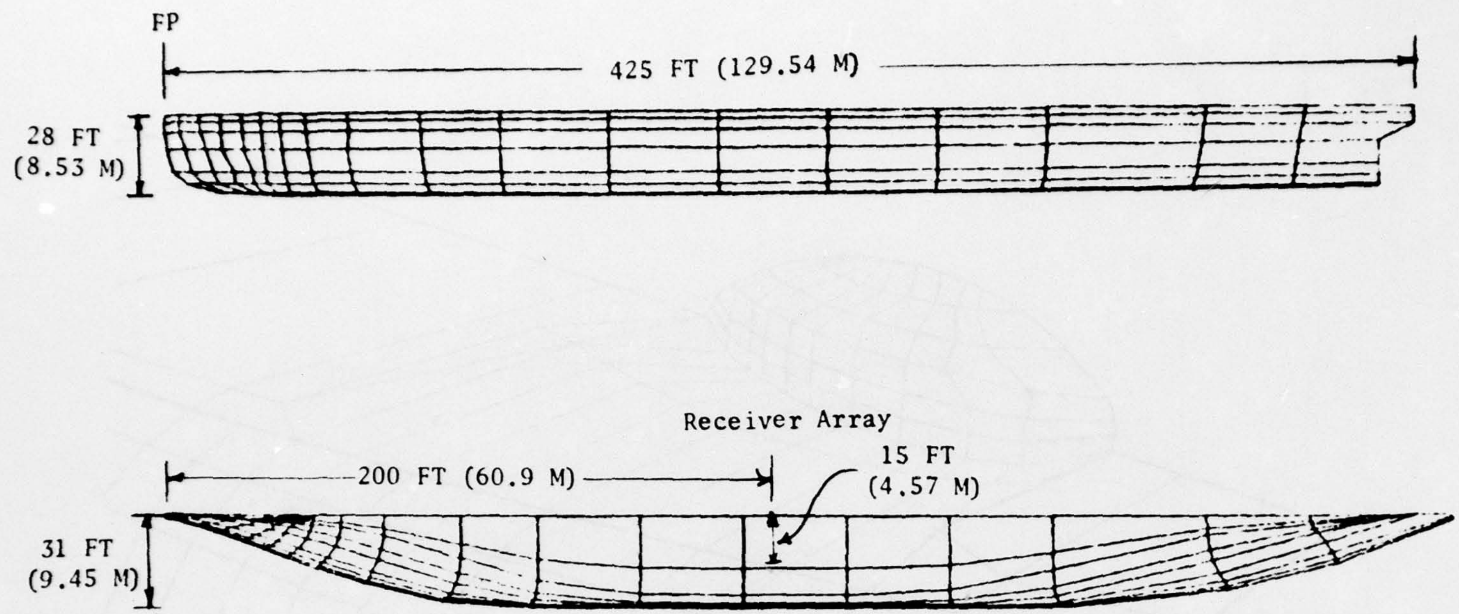


Figure 3 - Side and Bottom Views of Ship Lines for Calculations 3 and 4

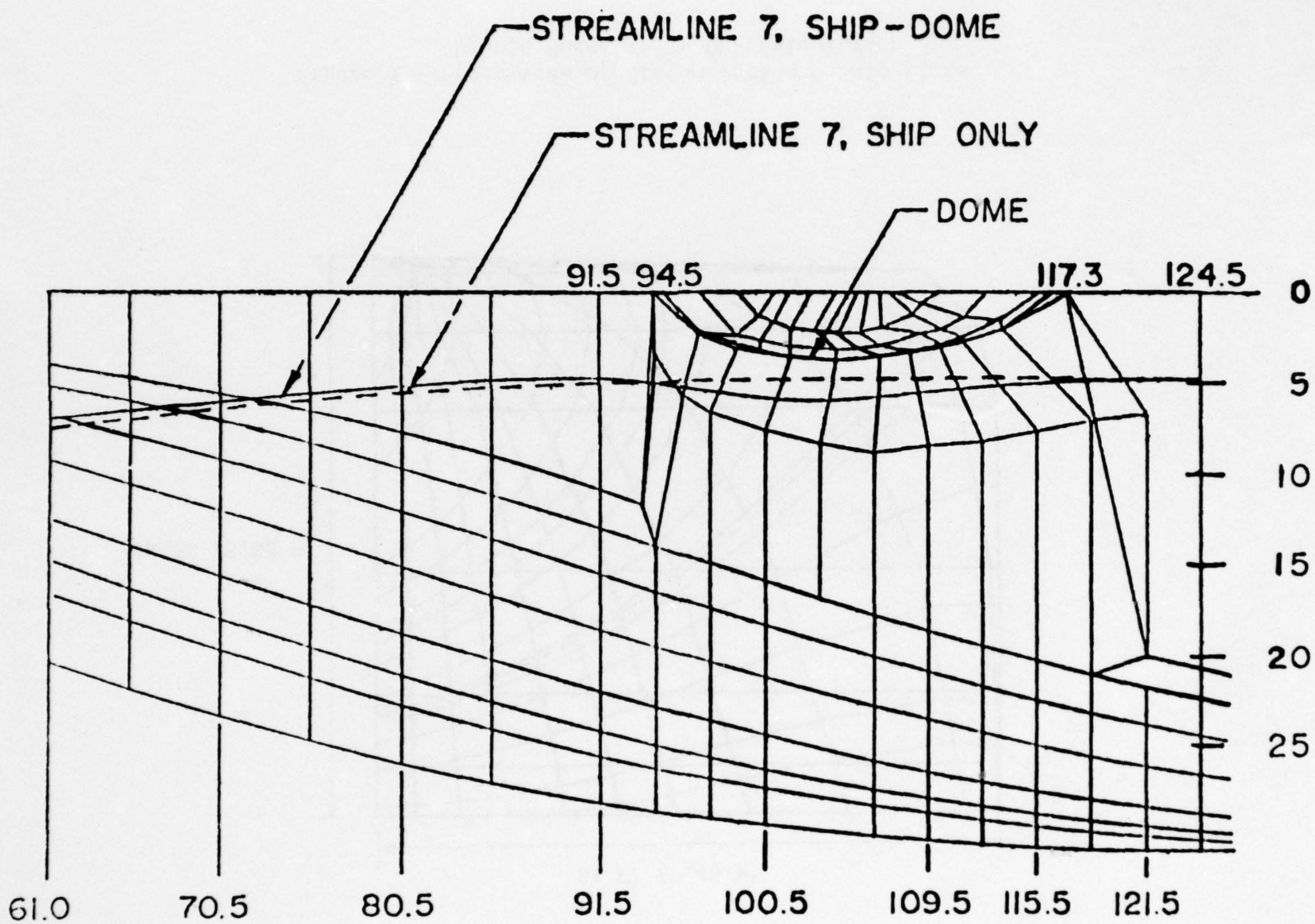


Figure 4 - Bottom View of Streamline 7 for Calculations 1 and 2 and Ship-Dome Lines for 60 FT $\leq$ X $\leq$ 125 FT

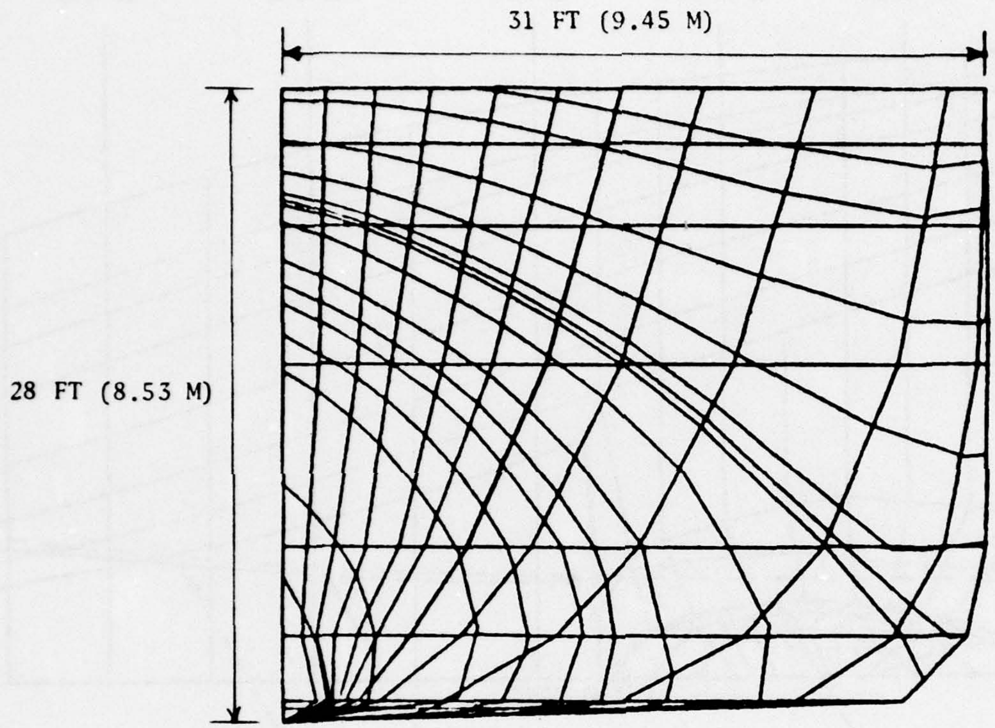


Figure 5 - Front View of Streamlines and Ship Lines
Double Model ($F_n = 0$) - Calculation 3

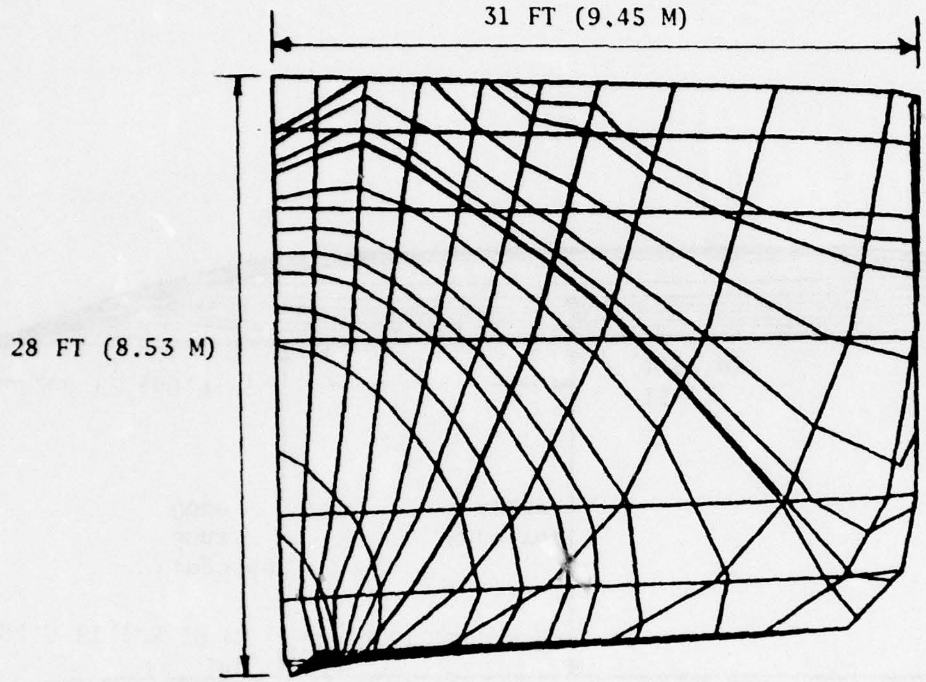


Figure 6 - Front View of Streamlines and Ship Lines
(Fn = 0.231) - Calculation 4

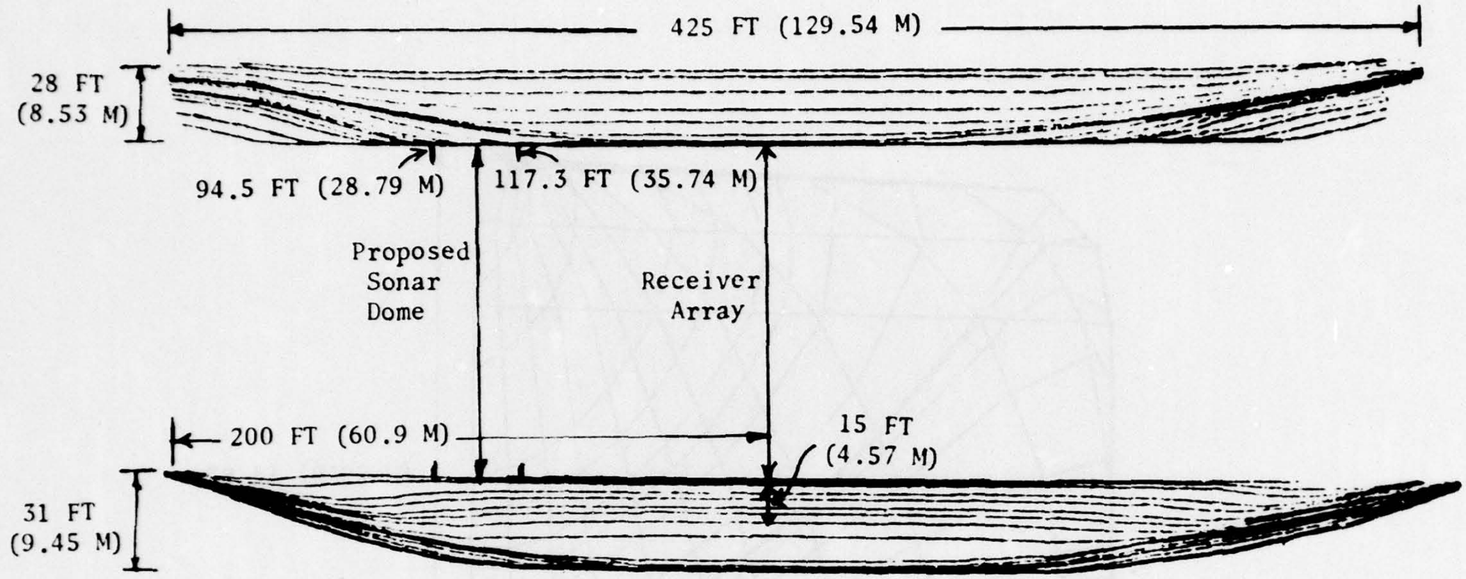


Figure 7 - Side and Bottom Views of Streamlines Only -
Double Model (Fn = 0) - Calculation 3

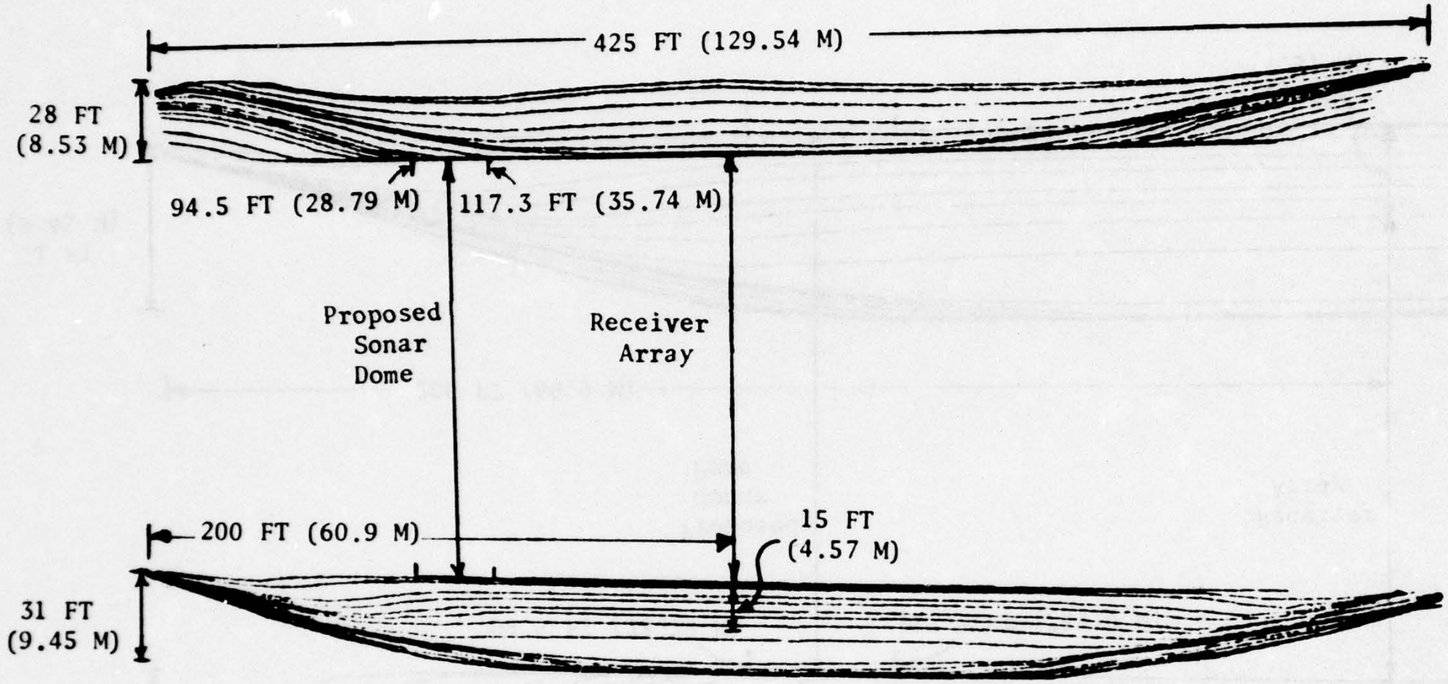


Figure 8 - Side and Bottom Views of Streamlines Only
(Fn = 0.231) - Calculation 4

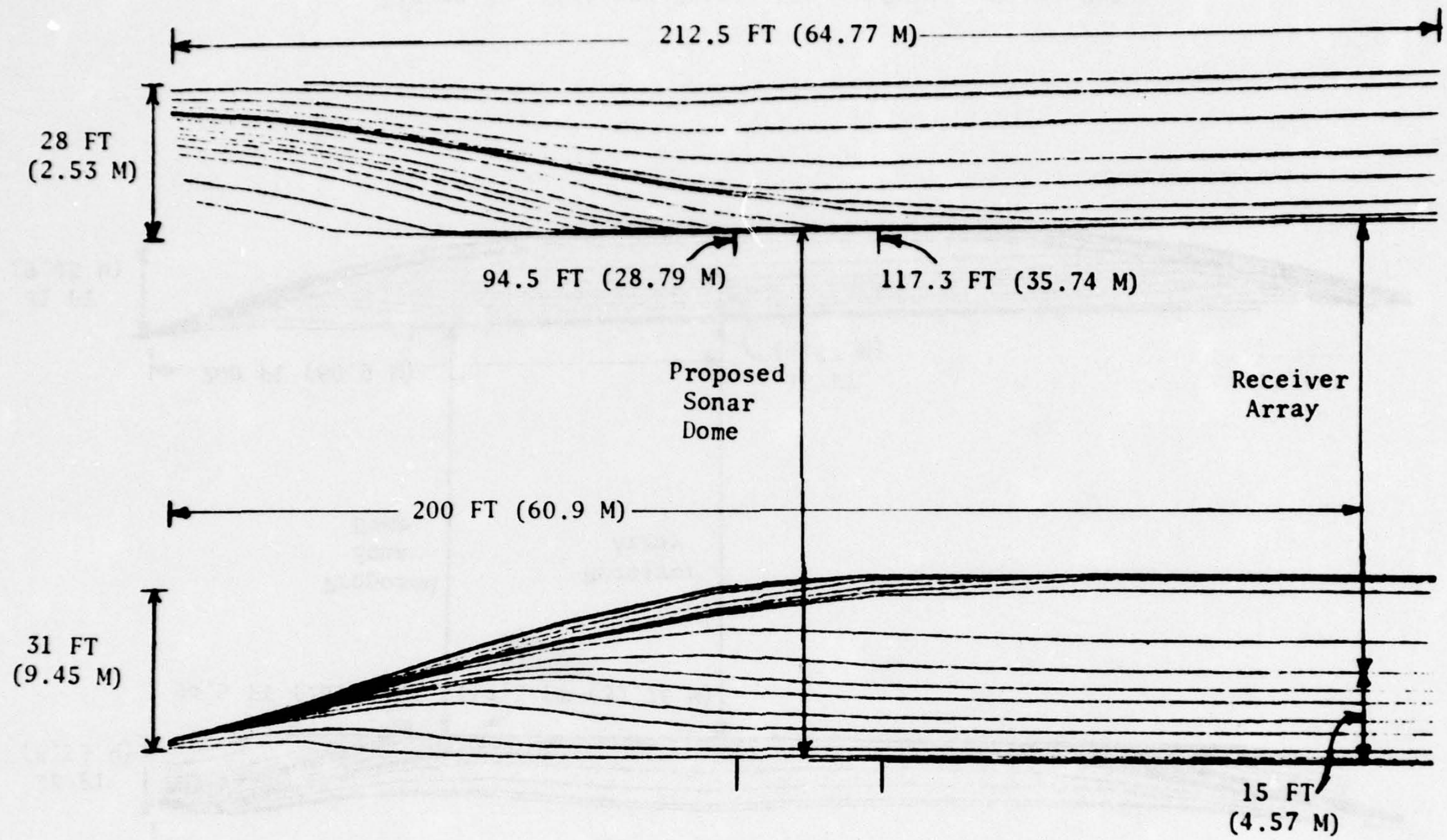


Figure 9 - Side and Bottom Views of Forward Half of Streamlines Only - Double Model (Fn = 0) - Calculation 3

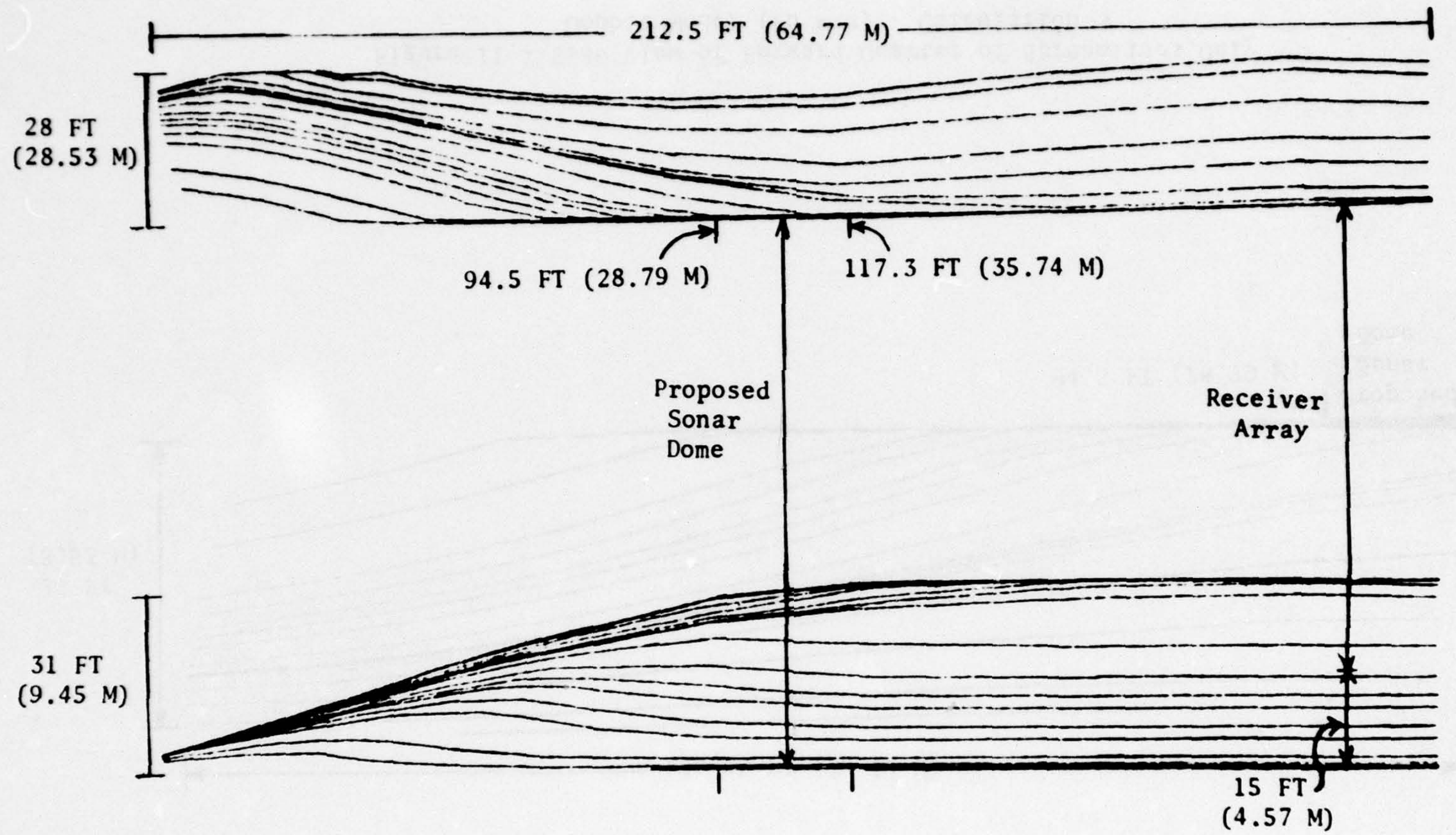


Figure 10 - Side and Bottom Views of Forward Half of Streamlines Only
(Fn = 0.231) - Calculation 4

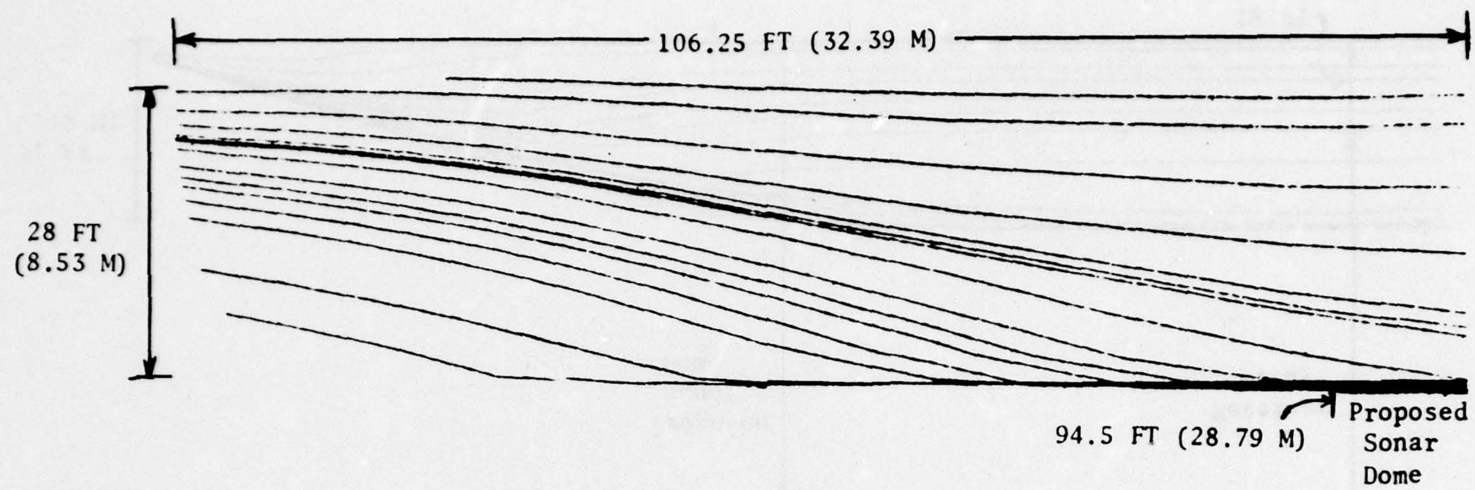


Figure 11 - Side View of Forward Quarter of Streamlines Only
Double Model (Fn = 0) - Calculation 3

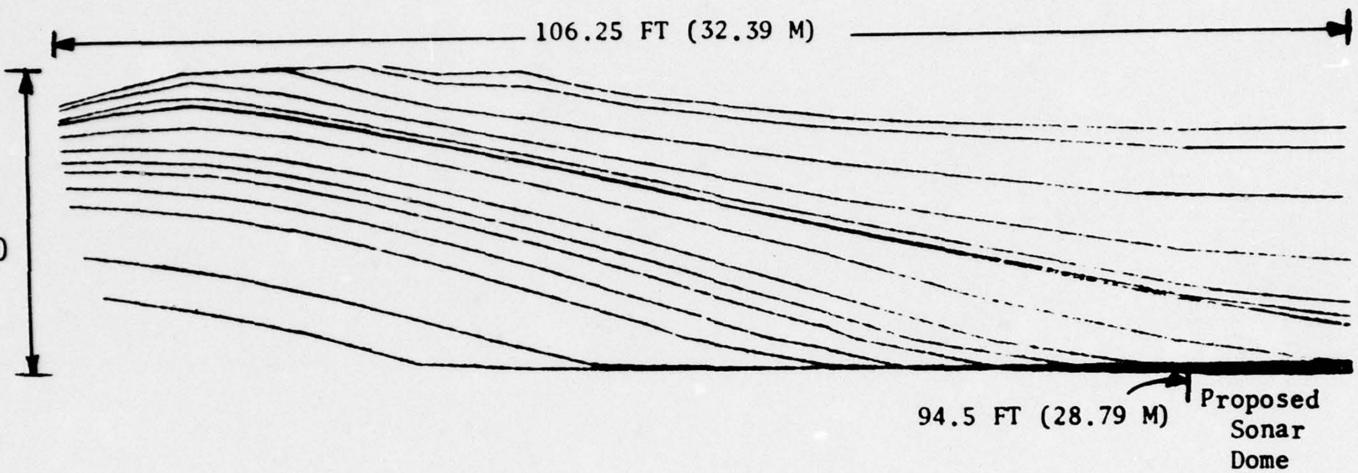


Figure 12 - Side View of Fourth Quarter of Streamlines Only
(Fn = 0.231) - Calculation 4

APPENDIX

DESCRIPTION OF FREE-SURFACE PROGRAM

The problem to be solved is the steady-state motion of fluid past a body in or near the free surface. The solution is to satisfy the exact body boundary conditions and a linearized free-surface condition on a limited region near the body. The problem is three-dimensional but it is best to start by describing the method for two-dimensional problems.

The velocity field is written in terms of integrals of a source density over the body surface, the surface of the image of the body above the free surface, and the limited region of the undisturbed free surface. The surfaces are divided into panels and the source density is approximated by a constant in each panel so that the integrals are replaced by a sum over the panels. An approximation to the linearized free-surface condition is obtained by applying a one-sided, upstream, finite difference operator to the velocity at the centers of the panels. The use of upstream differences prevents waves from developing upstream from the body. Upstream differencing cannot be used for the panel farthest upstream so the source density there is set to zero. The free-surface equations, together with the equations for the body boundary condition, now completely define the source density and are solved simultaneously so that all conditions are satisfied.

Experiments with two-dimensional problems have shown the following:

1. Two and three-point difference operators cause damping of the waves downstream from a disturbance. A four-point difference operator which eliminates errors from second and fourth (but not third) derivatives provides reasonable conservation of wave height. A five-point operator which also eliminates errors from the third derivative conserves wave height reasonably well but is not as good with few panels per wave length (8 to 12) as the four-point operator.

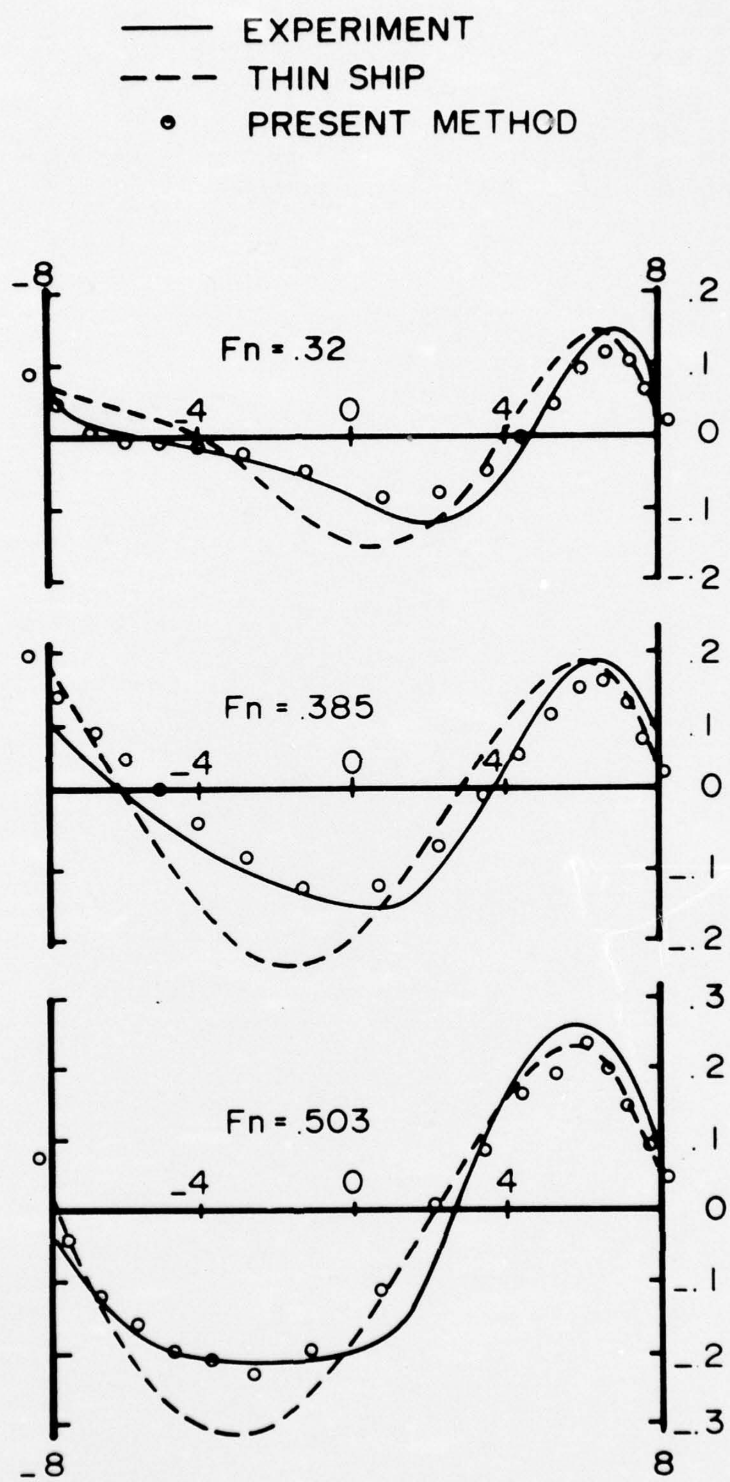
2. The wave length will be about 9 percent short.

3. A small damping region (about 1/8 wave length) is needed at the downstream end of the free surface source panels to prevent noise caused by the abrupt stop in the source density.

4. Linearization of the free surface with the velocity from the double model problem (the free surface treated as a plane of symmetry) is considerably better than linearization with the free-stream velocity when the body is close to the free surfaces.

For three-dimensional problems, the free surface condition is written in terms of derivatives taken along streamlines of the double model solution. Upstream differencing can then be used in an approximation to the free-surface condition on each streamline. Double model linearization is used so that the streamlines go around instead of through the body, as well as for increased accuracy. Thus, the solution of the three-dimensional problem is very similar to the solution of the two-dimensional problem except that there are sets of surface panels with each set following a streamline.

A computer program for three-dimensional problems has been completed and tested on Wigley Model 1805A. This model is a thin ship-like body with a length-to-beam ratio of 10 2/3. The surface profiles along the hull for Froude numbers 0.32, 0.385, and 0.503 are shown in the figures together with experimental measurements and thin ship calculations. The ship was represented by 64 panels, 16 in length by 4 in depth. The local part of the free surface was represented by 224 panels with 8 streamlines and 28 panels per streamline. The solution for one Froude number took 10 minutes on a CDC 6400 computer at a cost of $80.00.



Wave Profiles for Wigley Model 1805A

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